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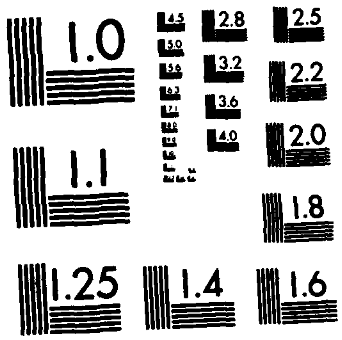

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Hands Coordination in Data Entry with a Two-Hand Chord Typewriter

Technical Report

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Cognitive Psychophysiology Laboratory

Prepared for:
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Block 20 - Abstract (continued):

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ABSTRACT

This paper describes the results of an experiment conducted to investigate the process of acquisition and operation of a data entry skill based upon a newly designed two-hand chord keyboard. This keyboard represents an effort to identify effective alternatives to the existing typewriter. It is consisted of two separate 5-key panels (one for each hand), and characters on each panel are entered by typing chords composed of one to five fingers. Each panel is capable of producing the full dictionary of characters, and hence can be considered to be an independent typewriter. Three important questions raised by this design are (a) the best coding principle represent identical letters on the left and right panels, (b) the duration of the initial acquisition period, rate of progress, and final levels of performance on this system, (c) the nature of coordination between hands in simultaneous chord production.

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The last decade witnessed a renewed interest in a systematic investigation of typing as a model task representing the more general class of transcription skills such as piano playing, writing, speaking, or data entry with computer keyboards (e.g, Norman & Rumelhart, 1982; Gentner, 1982, Cooper, 1983; Schaffer, 1978; Logan, 1982). The reasons for this interest are both theoretical and practical. The study of typing behavior appears to provide an attractive opportunity to examine theories and concepts of skill acquisition. Moreover, typing is a highly complex perceptual motor skill requiring the coordinated performance of two very different basic mechanisms, namely, semantic processors and motor controllers. These theoretical questions can be investigated in the context of typing with considerable ease especially as highly experienced subjects (typists) are easy to obtain. In addition, advanced laboratory facilities, computer technology, and fast photography enable a fine graded examination of task behavior.

The practical value of this research is evident given the rapid proliferation of computer systems in all areas of our daily activities. Wandering through computer shops around the United States, one is still amazed by the number and age of children interacting with the various demonstration units at any single shop. These shops have clearly taken the place of the traditional toy shops as the major place of interest for these youngsters. Every one of these units includes a data entry keyboard in one form or another. Human-machine interfaces with engineering systems, at all levels, are not lagging far behind. Most of the newly designed systems include a data entry keyboard and some reference to a background computer.

Naturally, typing on the standard keyboard using commercial type units has received the greatest measure of attention. While the merit of these studies is evident, we see a need to augment and compare this research with the study of typing skills using radically different devices. We further argue that if such a research is not conducted, our understanding of the basic faculties of transcription skills may be biased by the specific characteristics of the standard keyboard design. These biases may also constrain our efforts to develop better solutions to the persistent problem of communicating with computers via a data entry keyboard.

This claim is based on the assumption that the structure of every skill is strongly influenced by the physical characteristics and the operational constraints of the environment in which it is developed. Typing skills reflect, therefore, the coping strategies of the human organism with the design characteristics of the standard typewriter. Most of the existing data entry keyboards follow the "Q-W-E-R-T-Y" arrangement suggested by Christopher L. Sholes in 1873. Thus, the beginning of 1983 marks the end of the first decade, of the second century, in which the Sholes' design dominates the typing field. The main features of this design from a human performance viewpoint are:

a) Every letter and character is entered by a separate key (although some keys may have more than one function), leading to a large size keyboard with several rows of keys.

b) Each finger is responsible for several keys (letters).

c) Each hand and finger is responsible for an exclusive set of characters.

d) Typing of most words requires considerable hand and fingers travel within the coordinates of the keyboard.

e) Single printing head forces serial sequencing of the final outputs, even when other elements allow parallel entries.

These design characteristics were determined by the technological constraints of the era in which the typewriter was invented--mid 19th century, the golden age of mechanical engineering. Despite the fact that over the years all the hardware components of the typing machine has changed, the keyboard interface remained unchanged. Compare, for example, the above design features with the single hand typewriter described by Gopher and Eilam (1979), or with the two-hand chord typewriter which is the system under study in the present research (see Figure 1).

Insert Figure 1 About Here

This keyboard consists of two separate 5-key panels (one for each hand). Letters on each panel are entered by typing a single chord composed of 1-5 keys pressed together. Each panel can produce the full alphabet, and hence can be cosidered to represent an independent typewriter.

The main features of this system are:

a) There are only five keys for each hand, and each finger always rests on its corresponding key.

b) No travel of hand and fingers is required, and no exertion of large muscles.

c) Letters are identified by a combination of keys, and entries are produced by typing chords. Hence, both memory and response requirements have been changed.

d) Each hand can produce the full dictionary of characters. Thus, in principle, operate independently.

e) The system enables parallel entry and display.

It is quite obvious that these design characteristics constitute a radical change in the task requirements, while still residing within the same general problem area of transcription skills. Two main questions arise in introducing such a system:

a) What are the similarities and differences between the dimensions of skill developed on the chord keyboard and those acquired on the standard typewriter? In other words, what are the elements of the skill that reflect the inherent properties of the human processing system and, therefore, would remain uncanged on the two systems. And what are those that are determined by the specific constraints

of the operational environment and should, therefore, be changed considerably.

b) Can we facilitate training and improve overall typing performance with the new degrees of freedom given to us by modern technology?

However, before these two issues can be studied, an initial question has to be answered. What is the best principle to represent the code for the same letter on the two panels? For example, if the letter "A" is represented on the right hand panel by a chord composed of the thumb and index fingers (first and second keys counted from left to right); what will be the appropriate code for the letter "A" on the left hand panel? Two possible principles come immediately to mind:

a) Hand Symmetry--according to this principle, the same letter is represented on the right and left panels, by the symmetrical fingers of the hands (for example, the letter A is represented by the thumb and index fingers of each hand).

b) Spatial Congruence--according to this principle letters are represented by their pattern of key arrangement of the two panels (for example, "A" will now be entered by pressing the first and second keys on the right and left hand panels, with keys counted from left to right). Thus, while a Hand Symmetry code is based upon a body reference point and proprioceptive information. Spatial Congruence is based upon an external arrangement and spatial information (the two coding principles are demonstrated in Figure 2, together with their combination in the vertical position, which is discussed below). It is important to note that these coding principles constitute two fundamentally different representation formats of action plans in long term memory. Formats that are the heart of an ongoing debate in current motor theory (e.g., Kelso & Wallace, 1978; Gopher, in press). Note also that the two principles create mirror images of each other on the two panels, either in terms of spatial patterns or operating fingers.

Insert Figure 2 About Here

The study of the two principles is of a high theoretical value may be of lesser practical merit, because there is one spatial position in which the two are united.

c) Combined in Vertical Position--if the two chord panels are tilted vertically (or upright from their flat horizontal position) the conflict between the two representation principls is resolved, and the two unite (see Figure 2). The question is, of course, whether such a unification provides any advantage over the better of the two other arrangements. Note that placing the keyboard panels at an upright position not only resolves the representation conflict, but also constitute a better ergonomic posture for the hands (Kromer, 1972).

The experiment reported in this paper is devoted to the study of the effects of using the three principles, on the coordination between hands, and the acquisition of a data entry skill.

METHOD

Task:

In the initial phase subjects were presented with charts describing the letter codes relevant to their respective conditions (i.e., hand symmetry, spatial or combined, see Figure 2). They were required to memorize the 26 letter codes of each hand. During this phase, they could press various letter patterns on the keyboard and the respective letter would appear on the display.

Following this stage and throughout the seven experimental meetings subjects were required to respond as quickly as possible to letters presented on the display with the appropriate codes. The letters were presented singly, on the left or right side of the display, or dually. Subjects were required to respond to stimuli presented on the left side of the screen with the left hand, the right side of the screen with the right hand and to dual presentation with both hands.

Trials were organized into mixed or dual blocks. In mixed blocks the subject was presented with an equal number of single (left or right) and dual letter trials. In these blocks the full 26 letter alphabet was used. In dual blocks the subject was presented with dual stimuli (left and right) every trial. However, only a limited eight letter set was used. The eight letters selected for use suggest some interesting compatibility and conflict issues, that would be elaborated on in the result section. The trial format was the same for both mixed and dual letter blocks. There was a warning signal 800 msec before the appearance of a letter. It informed the subject on the nature of the coming trial (single or dual), and if single, whether the letter would be presented on the right or left side. There was then a 300 msec presentation of the letter stimulus, followed by another 1700 msec response interval, and feedback was given to the subject on his performance.

Apparatus

The experiment was governed by a PDP 11/40 computer system. Letters were presented on a plasma panel display. Responses were entered through the two-hand chord keyboard (Figure 1) and recorded directly onto magnetic tape. The keyboards were positioned horizontally for the hand symmetry and vertically for the combined condition. Hand rests were added in the combined condition. The keyboards were situated between the subject and the plasma board display.

The letters presented were 1/2 cm tall and 1/4 cm wide. In the dual presentations the letters were 4.2 cm apart. The line of sight distance was approximately 60 cm. The visual angle for the single stimulus was approximately .45 of a degree The visual angle between the stimulus was approximately 3.75 degrees. In addition to behavioral measures, electrophysiological measures were taken during meetings 3-7. The electrode sites were Fz, Cz, Pz, C3, and C4. EOG measures were taken to correct for horizontal and vertical eye movements.

Procedure

The subjects participated in 7, 1.5 hour training sessions. The first session was dedicated to code acquisition and initial familiarization. Meetings 2-7 followed the same format: 8 mixed blocks of 52 trials followed by 2 dual blocks of 64 trials. In a given meeting there was a total of 416 mixed trials and 128 dual trials resulting in a total of 544 trials per meeting. In addition to the mixed and dual blocks, meetings 2, 4, and 7 also included a control task. This task involved the presentation of the same letter for 32 trials. There were two blocks; one to the left hand and one to which the right hand responded to singly. This control task was used to estimate simple reaction time without the cognitive processing of letter codes.

Subject performance was motivated with a bonus system. In this system both speed and accuracy were emphasized. Subjects received $1.50 bonus for every 10% improvement in their response time. However, a bonus was awarded only if the percentage of errors per block of trials did not exceed 5%.

Subjects

Subjects were 12 right-handed male college students with English as their native language. They were payed for their participation at a rate of $3.50 pe hour, and received additional bonuses based on their performance. Subjects were assigned randomly to the three experimental groups.

RESULTS

In the present paper we limit our description of results to the main performance data obtained for the three experimental groups.

Initial Memorization

The initial phase under all conditions was memorization of the 52 letter chords on the two hands. Subjects were given a complete freedom to use their own methods to study and memorize the alphabet.

The general finding of this stage was that subjects in all groups could memorize the codes within 35-40 minutes, to a criteria that they could produce any letter upon request. There are some indications that subjects in the vertical-combind group have mastered the codes even faster. At the end of 40 minutes subjects could, therefore, be presented with letters on the display, to which they reacted in a mode similar to touch typing on a regular keyboard. It should be recognized that because each of the fingers always rests on its home key, once the codes have been comitted to memory, no further visual supervision is required.

Acquisition

Figures 3 and 4 depict the learning curves of single and dual letter entries for one subject who practiced under the vertical-combined condition. These curves are typical to the learning functions of the majority of subjects, and show a continuous improvement throughout the meetings, with no asymptote yet encountered. From the results presented for this subject in Figure 3, and from the average results presented in Figure 5 it can be observed that at the 7th meeting, single letter entries reach the level of 550 to 660 msec with a small but reliable advantage to letters entered by the left hand. Such an advantage was observed in the performance of

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Insert Figures 3 & 4 About Here

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subjects in all groups. Its average size was 65 msec ($t(8) = 5.76$ p .001).

When a pair of letters was presented, the left hand letter was [illegible]ally entered first. This outcome can be clearly observed in Figure 4 and typical to the performance of subjects in all experimental groups. [illegible]o inbound curves in this figure represent the average entry time for t[illegible]ft and right hand letters under dual letter presentations. Entry times improved regularly on both hands, and the time to complete a pair reached, for this subject, an average level of 800 msec at the end of the 10 hour training period. A level which compares with a typing rate of 150 characters per minute.

The lower curve in Figure 4 is a replot of the entry times of single letters with the left hand. It demonstrates the existence of a small but consistent delay in the beginning of typing under dual letter presentations. Similar delays were evident for all subjects, but were much more pronounced in the hand symmetry group (see Figure 5). The upper curve in Figure 4 represents the additive values of single letter entries (left and right) at each time point (block of trials). It was computed to examine the development of parallel entry capabilities for dual letter presentations. The difference between this curve and the entry times of the right hand letter (the second in a pair) can then be expressed as a percent of saving due to response overlap in dual letter entries. For the subject whose data is presented in Figure 4, this saving was 26%, at the end of the 7th meeting.

Differences Between the Three Representation Principles

Figures 5 and 6 summarize the main differences in performance between the three experimental groups, at the last experimental meeting. These plots are based on correct responses only. Because subjects received a bonus for improved speed only when errors were less than 5%, the general error percentage in all groups was low (about 3%). Error distributions did not show any reversed trends due to speed accuracy tradeoff, and are therefore omitted from the present discussion.

Figure 5 depicts the results obtained in mixed experimental blocks, in which trials included an equal number of single and dual letter presentations. Four data points are plotted for each group: 1) average time for tapping, 2) single letter entries (left and right entries were averaged for both of these measures), 3) the time to type the first letter in a simultaneous pair, and 4) the time to complete a pair. As can be seen,

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Insert Figure 5 About Here

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the three groups did not differ in the speed at which subjects could perform a simple reaction time task (tapping) on the keyboard. In single letter conditions the hand symmetry group appears to be slower than the other two groups, but this difference did not reach statistical significance ($F(2/9) = 1.12$, $p < .37$, $F(2/9) = 2.254$ $p < .16$ for single left and right letters respectively).

Large and reliable differences between groups appeared in dual letter entries. In both the time to begin and the time to complete the entry of a pair, the hand symmetry group was considerably slower than the other two groups ($F(2/9/ = 4.93$, $p < .036$, $F(2/9) = 6.63$, $p < .017$ for beginning and completing a pair respectively). In addition, the vertical-combined group was faster than the spatial group in the time to complete a pair.

The same pattern of results appears in Figure 6 which depicts the results from blocks composed only of dual letters presentations. Aside from including only pairs of letters, these blocks differed from mixed blocks in two additional important features. First, they incorporated only a limited set of 8 letters, while the complete set of 26 letters, in equal probabilities, was presented in mixed blocks. Secondly, these 8 letters included only chord combinations of one to three fingers that were relatively easier, as determined from their response times in single letter trials. The objective of selecting these letters was to provide enough data points to contrast specific combinations of interest. For example, comparison between pairs of the same letter that have the same chord pattern under hand symmetry or spatial congruence conditions, versus those that create a mirror imagery of each other on the two hands and, therefore, represent a conflict situation (see Figure 7). Simple chords were selected to separate the study of a conflict in representation principle from the issue of coordinating difficult motor chords. The results plotted in Figure

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Insert Figure 6 About Here

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6 clearly indicate that even with a limited and simplified set, the hand symmetry group was considerably slower than the other two groups, and that the subjects in the vertical-combined condition were still faster to

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Insert Figure 7 About Here

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complete a pair entry ($F(2/9) = 3.88$, $p < .06$; $F(2/9) = 8.83$, $p < .008$ for the first and second letter in a pair respectively).

Figure 8 presents the differences between the three groups at the seventh meeting, in their ability to overlap responses in dual letter trials. To recapitulate, this ability was calculated by comparing the time to complete a pair entry, with the time to enter a left and a right letter in succession. In essence, this measure provides an estimate of the developed time-sharing capabilities in the three groups. Here again, the hand symmetry group lagged behind. As the figure shows the other two groups were not only better in relative terms, but also in their absolute levels of time saving, that were considerably larger than those of the hand symmetry group, despite their much shorter response times. The vertical-combined group was again better than the spatial congruence group. The F ratio for

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Insert Figure 8 About Here

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the differences in relative saving was 5.06, $p < .034$. The absolute differences failed to reach statistical significance ($F(2/9) = 2.37$, $p < .15$).

The last comparison to be described in the present paper, is between typing of pairs of the same letters, when the codes of these letters have the same spatial and hand symmetry arrangement on the two hands, versus those letters that create a conflict with regard to one of the two representation principles (see Figure 7). To state differently, the issue is, what is more confusing to type the same letters when different fingers have to be operated (spatial congruence), or to enter the same letters when they create a different spatial pattern (hand symmetry). Note that unlike previous comparisons, this analysis calls for a comparison within the performance data of each group. Thus, in the vertical-combined condition, when the same letters are presented to the two hands there always exist both a spatial and a hand symmetry matching. Under hand symmetry, conflicts occur because same letters create different spatial patterns on the keyboard. Under spatial congruence, they require the use of different fingers. Four letters were included in each of these groups (conflicting vs. nonconflicting). Table 1 summarizes the main results of this comparison. It is based on the combined data of subjects performance, in

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Insert Table 1 About Here

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meetings 5, 6, 7.

From inspecting this table it is clear that the performance of subjects in the hand symmetry group did not suffer much from the spatial conflicts. Their response times were about the same in the conflicting and nonconflicting groups of letters ($t(7) = .753$, $p > .475$). The same was true for subjects in the combined group, whose performance for the second group of letters was even slightly better ($t(7) = 3.343$, $p < .013$). In contrast, the performance of subjects in the spatial congruence group showed pronounced deterioration due to the requirement to type the same letters with asymmetric fingers ($t(7) = 4.703$, $p < .005$). Note however, that this deterioration should be only interpreted in relative terms, because the absolute levels of performance for the conflicting group were about equal for the hand symmetry and the spatial congruence groups.

DISCUSSION

The significance of the present results should be examined both from an applied and a theoretical viewpoint. Taken together, they showed that: a) subjects were able to perform in a touch typing mode, and memorize the codes for all letters, after a brief period of self teaching, b) that progress in learning was fast and included the development of parallel entry capabilities, c) that in general, representation of codes by spatial patterns was considerably better than coding by hand symmetry, d) that performance with an upright tilted panel was better than with a horizontal panel.

These findings raise the possibility that for many system applications, a chord keyboard of the type described in the present study, may constitute a viable and attractive alternative to the traditional typewriter or data entry keyboard. Touch typing ability and similar entry speeds on a standard keyboard, are the achievement of several months of daily practice (e.g., Hill, Rejall, & Thorndike, 1913; Dvorak, Merrick, Dealey, & Ford, 1936; Gentner, 1982). In light of the fundamental differences between the two typing keyboards in their skill components, one can conclude, that it appears to be easier for humans to commit 52 chords to memory and activate them upon request, than to learn the ways of the hand to a similar number of keys spread out on a typing keyboard. This conclusion is also supported by another line of experiments, with a single hand chord typewriter for the Hebrew language (Gopher & Eilam, 1979; Gopher, in press).

At this stage no claims can be made with regard to top or asymptotic typing speeds. It may very well be that a regular typing skill is harder to acquire, but it yields better performance when proficient. Our present argument is limited to the novice trainee, and the nonprofessional user. However, the results are provocative enough to encourage a comparative study with prolonged training. An important characteristic of the present keyboard from an application perspective, is that its major skill components are so different from those required in standard typing. Some of our subjects were proficient typists, but no interference or facilitation of performance could be associated with this fact. In different words, one can acquire and maintain the two skills side by side with little interference.

One other practical implication of the data that should not be ignored, is the improved performance with an upright keyboard. As has been argued in the introduction section, such an angulr tilt provides both a representation and an ergonomic advantage. The full impact of the latter factor was most likely not revealed in the present study, in which a special effort was made to minimize the effects of fatigue. The total duration of each experimental session was relatively short, trials were discrete, and subjects were given many intermissions.

The degrees of freedom given to us by modern technology enable us to consider such a change in the keyboard orientation with little impact on the total costs of system design and production. Should we wait for the process of natural evolution to develop a human mutant, whose hands are optimized for performance on flat panels? Or shall we take the initiative and change our panels to fit the ergonomics of the human hand? It is true that when visual monitoring is necessary, upright panels are deficient, but with chord

keyboards vision requirements are minimal. Moreover, even on the regular typewriter vision plays a heavy role only until proficiency is acquired. Then, motor factors constitute the major constraints on performance (Norman & Rummelhart, 1982). Can the panels be tilted at this stage to improve performance?

From a theoretical viewpoint, the most important finding was the robust advantage of a memory representation by spatial patterns over a representation by operating fingers, which was most pronounced when the two hands had to be coordinated in simultaneous activation. This advantage lends support to current theoretical views that argue that, at their upper level, complex action plans are represented by the spatial pattern that the corresponding movement creates in the outside world (e.g., Bernstein, 1967; Kelso & Wallace, 1978; Gopher, in press).

Additional support to the importance of the spatial patterns in the memorization and retrieval of motor chords, comes from data obtained by Nachum Fossfeld at the Technion in Israel, using the same two hand chord keyboard for the Hebrew language. Following the training of his subjects in letter typing (in a combined condition only). He required them to vocalize letter names in response to visually displayed chord patterns shown within a schematic drawing of the keyboard on a computer display. The correlation between the verbal response times to identify letters and the response times for actual typing of these letters was 0.73, indicating about 50% of common variance. Furthermore, these verbal response times correlated at a 0.93 level with the same responses made by a control group that did not receive any former training in typing on the chord keyboard. It, therefore, appears that the difficulty of recognizing and retrieving patterns is a main factor in the response variability of motor productions, even in the most advantageous condition (i.e., vertical posture).

There was only one exception in the results to the clear superiority of a representation by spatial patterns. When the same letter had to be typed by both hands, and its code required the operation of asymmetrical fingers, performance in the spatial congruence group degraded. A similar decrement was not observed in the contrasting case, when subjects in the hand symmetry group were presented with same letter pairs that create mirror imagery patterns on the two panels. A possible interpretation for this finding is that subjects find it easier to operationalize the meaning of the property "same" as associated with same fingers, than to relate it to the same spatial patterns. Such an interpretation also corresponds to the informal intuition of the vast majority of the visitors in our laboratory, which favors hand symmetry as a coding principle.

How can we reconcile the obvious inconsistency between this interpretation, and the clear superiority of the spatial representation principle in the majority of cases. It should be recognized that from the total number of 676 possible pair combinations of letters, pairs of the same letters are less than 4%, and conflicting pairs are only 3% of the total number of combinations. Hence, in the majority of trials, subjects were presented with letter pairs that differ both in their fingers and key arrangement. It is in those cases that subjects were better able to perform, based upon a spatial representation principle.

But why would it be more difficult to represent different chord patterns by their corresponding fingers? At this stage we do not have a definite answer to this question. However, we would like to propose a possible direction for such an answer. Suppose that the brain commands the operation of fingers, such that when fingers of one hand are activated, there is also an increase in the activation of the symmetrical fingers of the other hand. We are not aware of neurophysiological work that studied this question, but there is some behavioral research that supports the existence of symmetrical activation (e.g., Rabbit, Vyas, & Fearnly, 1975). It follows that when subjects are instructed to enter two different letters on the two panels, they have to activate different fingers on each hand, and at the same time inhibit the corresponding activation of the symmetrical but irrelevant fingers of the two hands.

For subjects in the spatial congruence condition, this latter requirement is consistent with their general rule of training. They are taught to ignore all hand symmetry considerations and concentrate solely on the spatial patterns created by the chords. In contrast, subjects in the hand symmetry group are subjected to an eternal, peculiar, double bind conflict. In entering different letters they are required, on the one hand, to inhibit the natural symmetrical activations of fingers on the two hands. At the same time they are called to memorize hand symmetry because this is the general representation rule that they draw upon. The only time that this conflict is resolved, is in the event that both hands have to enter the same letter. It is this combination that create the largest problem for subjects in the spatial congruence group. At this stage this interpretation is a post hoc speculation, and should be validated by direct manipulations of the relevant variables.

The last outcome to be discussed is the improved performance that was obtained when the keyboard panels were tilted to an upright position. The exact causes for this improvement cannot be determined from the results of the present experiment. The main question is, whether it should be attributed only a representation factor (because all conflicts between spatial and finger based representations are resolved). Or, whether there is an actual facilitation in the motor coordination of the two hands in the upright posture.

Note that the only difference between the best and the worst group of the present experiment was the angular position of their panels. If it is indeed a representation problem, can subjects in the hand symmetry condition be taught to visualize their panels in an upright position, and then the differences in performance between groups will disappear? If the keyboard panels of subjects in the vertical combined-condition are flattened at the end of their training, would there be an immediate, transient, or enduring change in performance levels? These are two of the questions that have to be answered in future research.

In conclusion, and despite the many uncertainties in the interpretation of the present results, they have proved both the applied and the scientific merit of continuing this venture. A different approach to the development of data entry devices is both feasible and useful. It may also provide convergent evidence on the ways in which our words command our hands.

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Table 1

Average response time (msec) for entering conflicting and nonconflicting pairs of the same letter (meetings 5-7, dual letter blocks).

		Hand Symmetry		Spatial Congruence		Vertical Combined	
		First	Second	First	Second	First	Second
Letters that do not conflict	$\bar{x}$	618.0	644.0	559.0	591.0	585.4	591.6
(E, H, N, S)	SD	77.2	62.3	24.8	35.3	30.6	37.9
Letters that create a conflict	$\bar{x}$	626.0	652.0	646.6	669.7	554.3	551.8
(A, U, I, T)	SD	59.9	38.3	79.2	74.8	40.8	35.85
Difference conflict-no conflict		8.00	8.00	87.60	78.62	-31.12	-39.81

Figure 1 - Top down view of the two-hand chord keyboard. Note that each of the plates can be rotated to any angular position from horizontal to vertical posture.

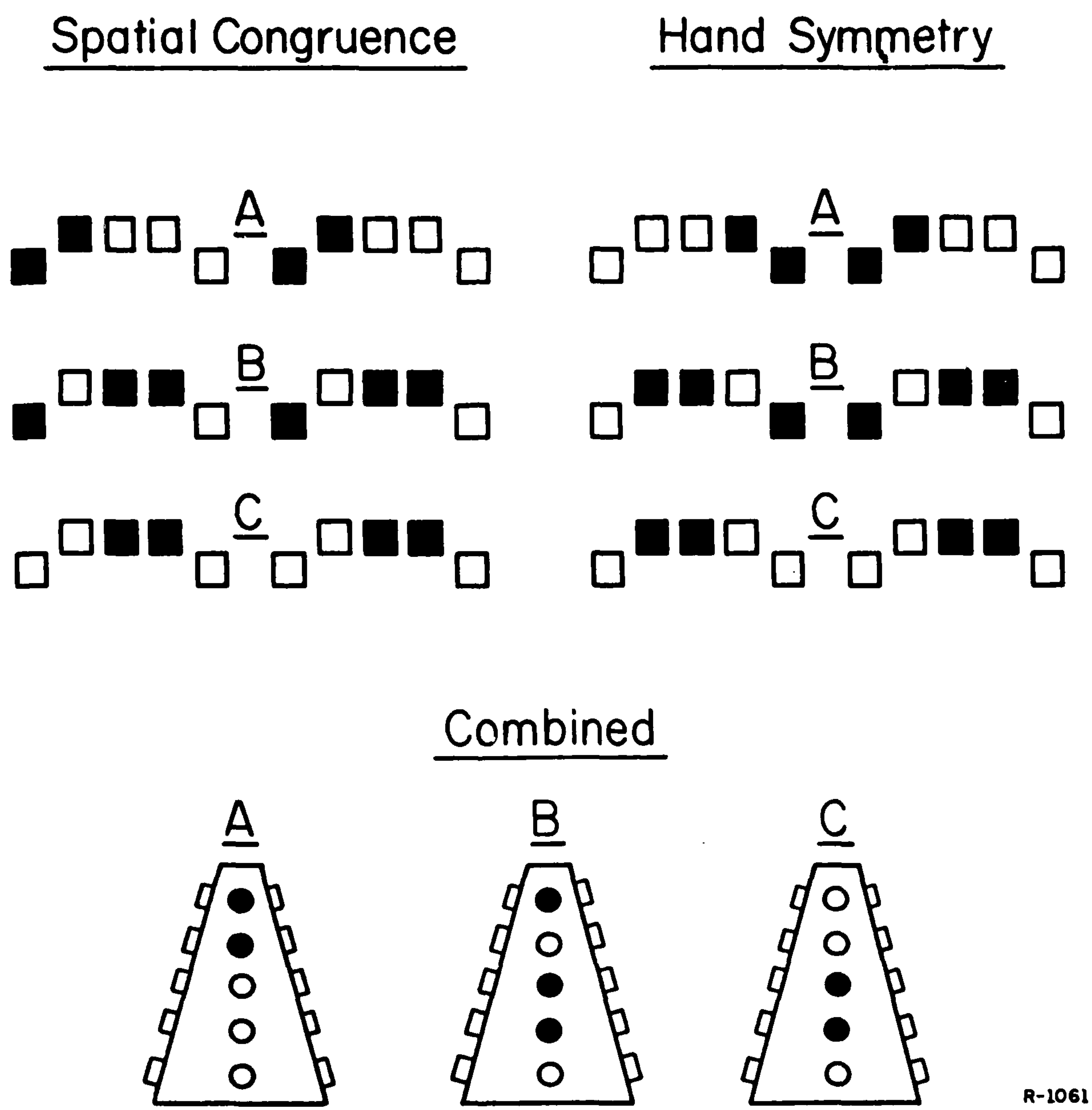

Figure 2 - Coding principles for associating letters with chord entries

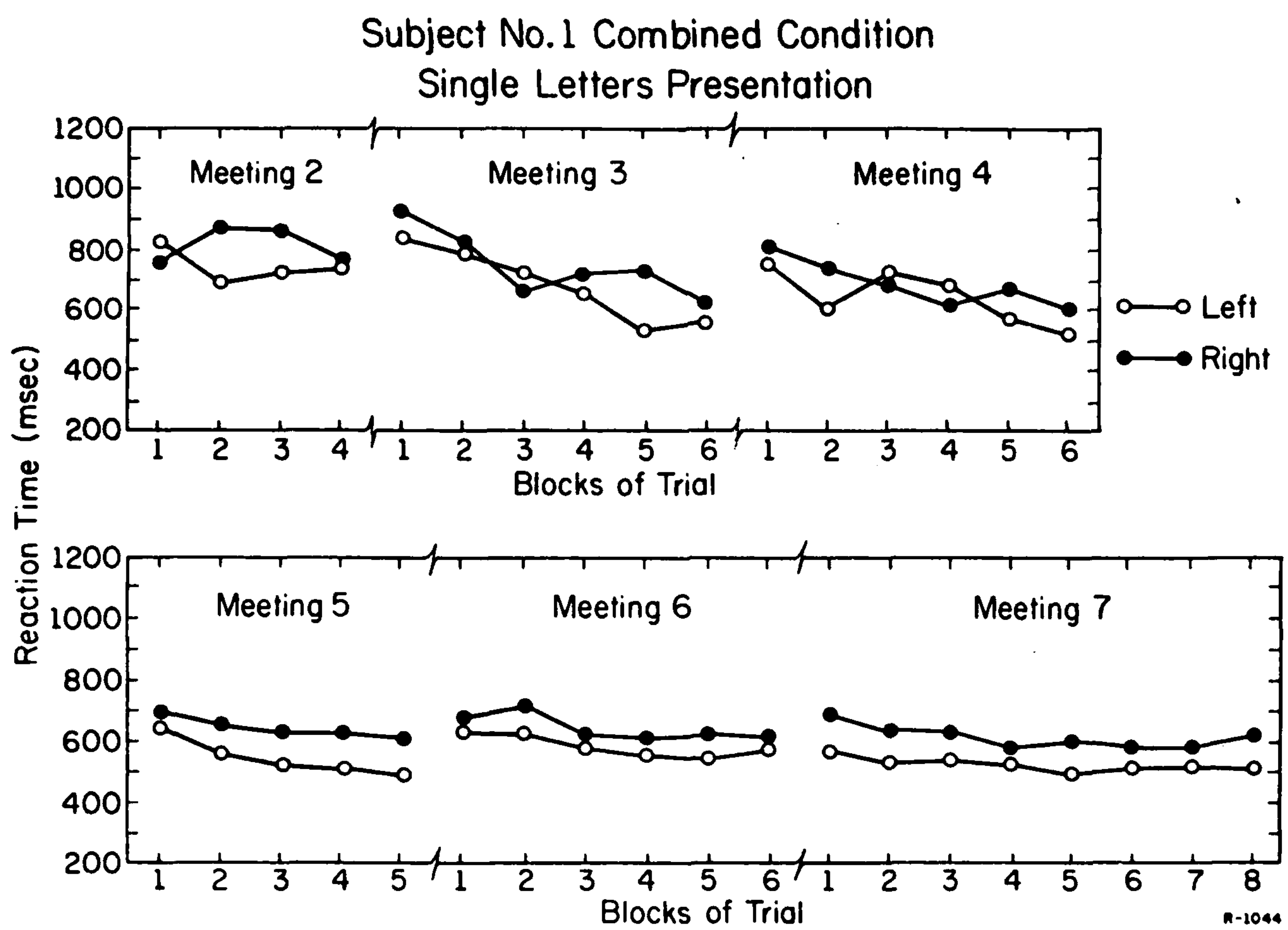

Figure 3 - The progress of training of one subject in single letter entries (averages for blocks of 52 trials)

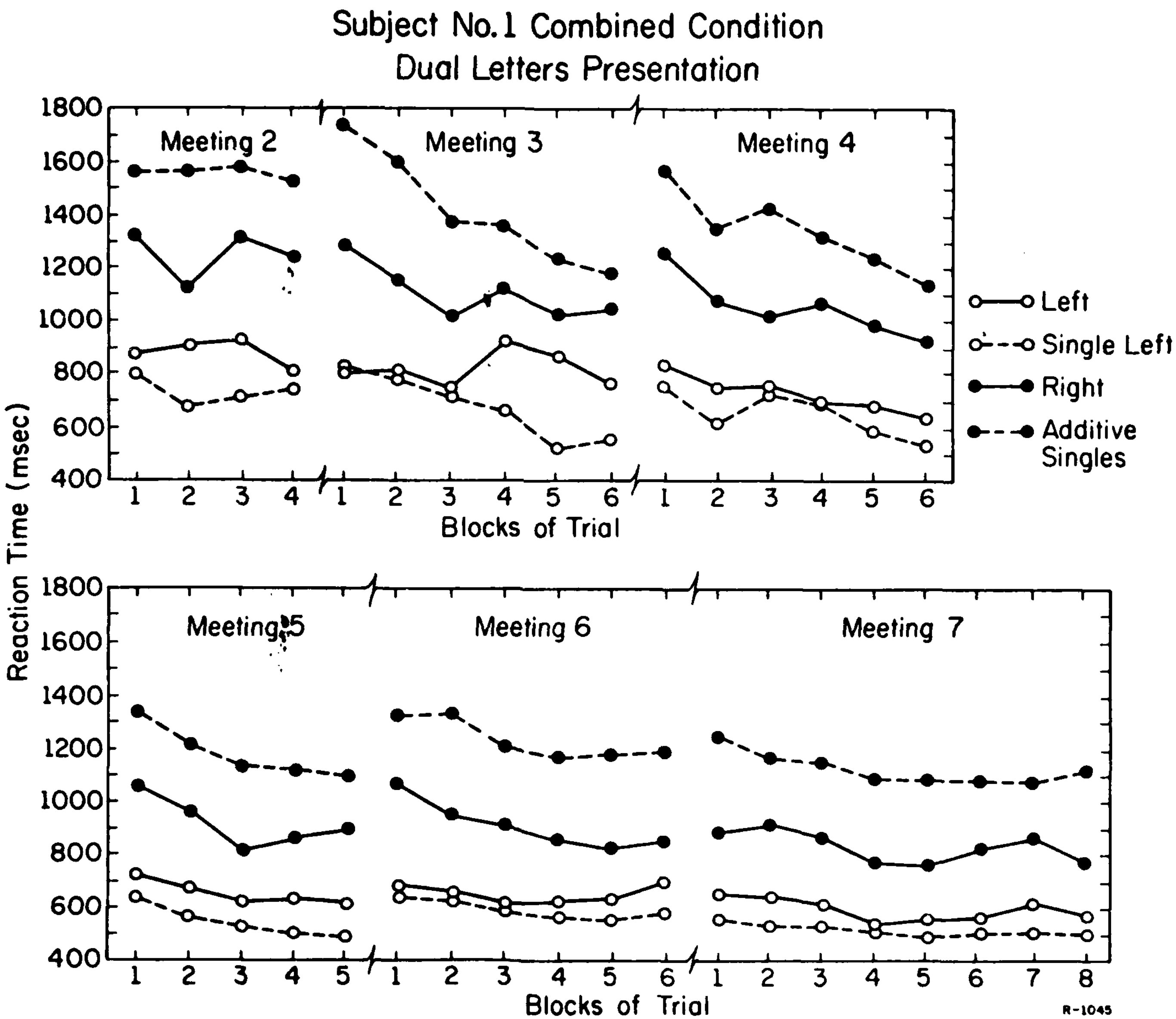

Figure 4 - The Progress of training for one subject in dual letter entries (mixed blocks, 52 trials in a block). The two inner curves represent the left and the right hand entries of a dual pair respectively. The lower curve is the time to type a single letter in single letter conditions. The upper curve is the time to type two letters in a sequence.

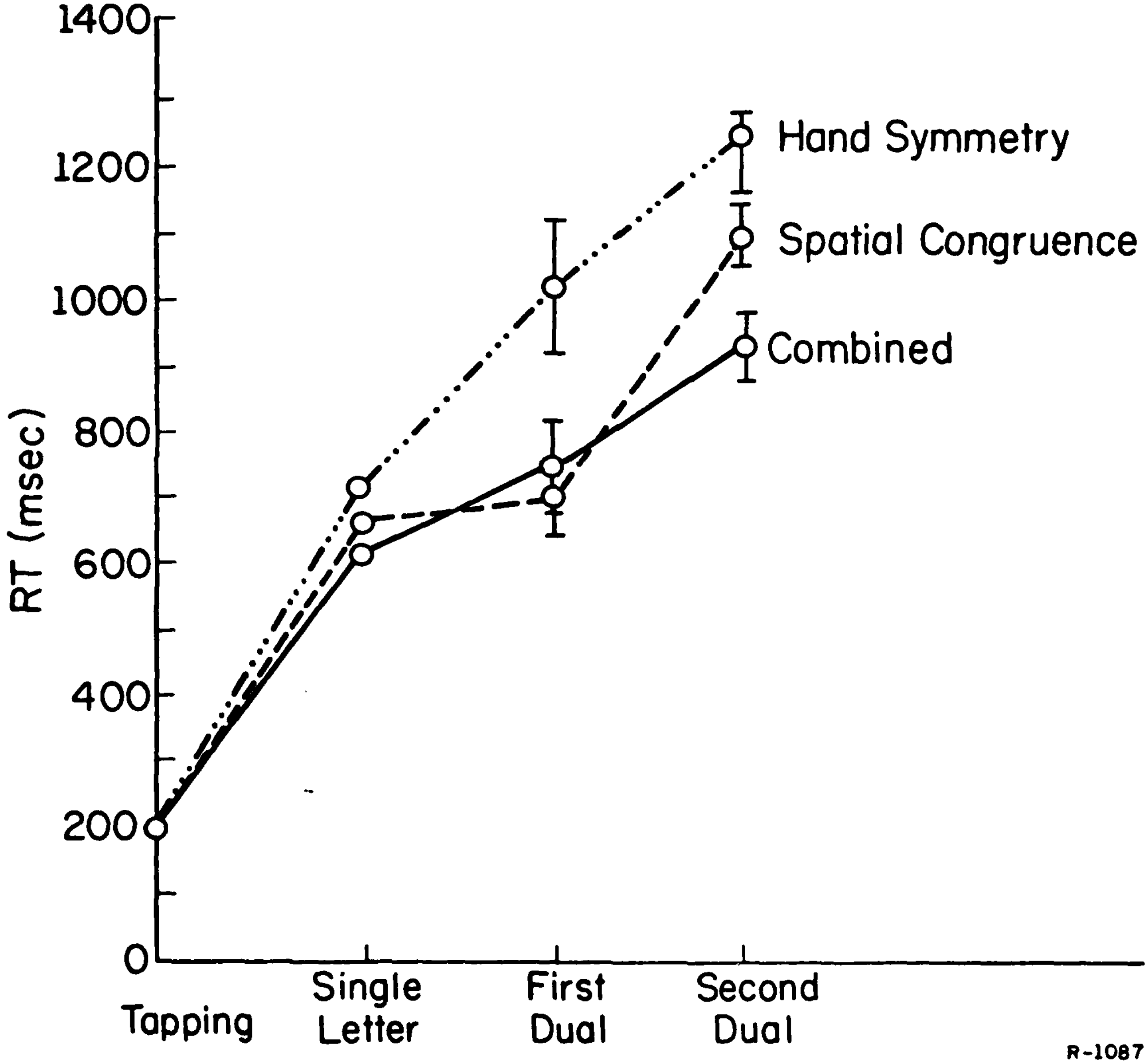

Figure 5 - Average response time to single and pairs of letters for the three experimental groups at the 7th training session

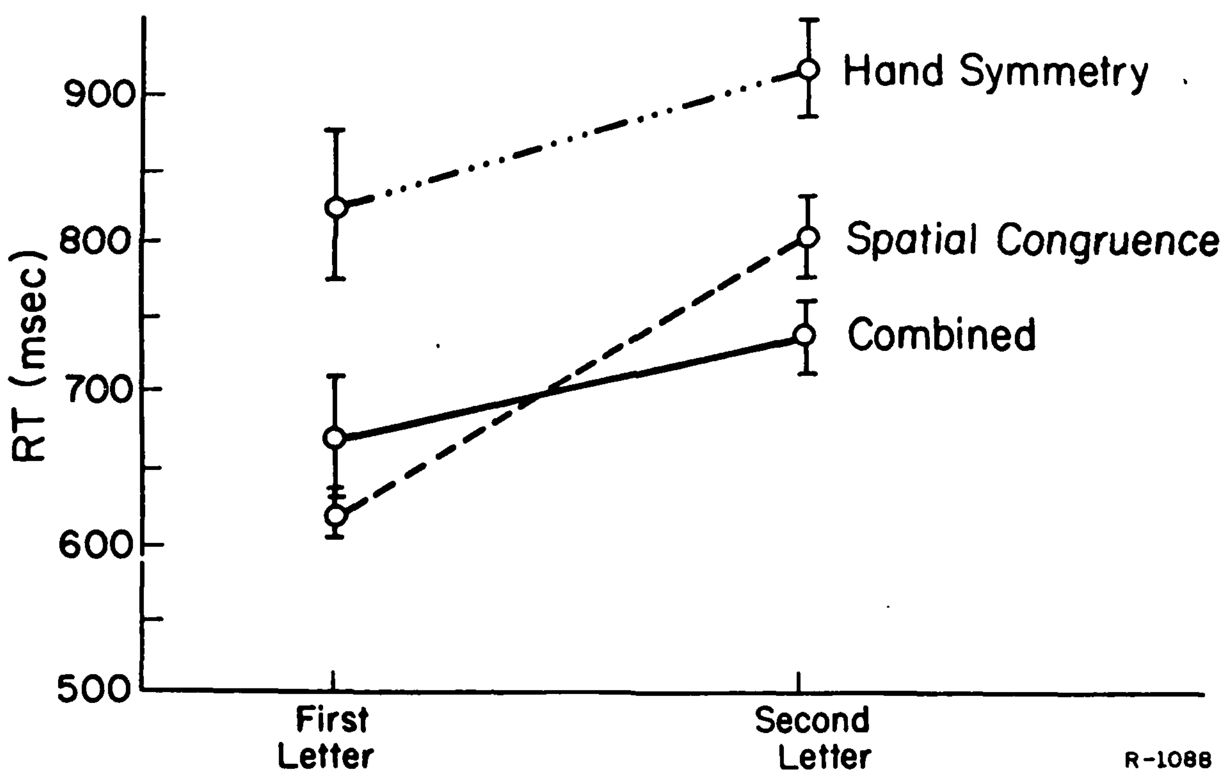

Figure 6 - Average response times in dual letter entries for the three experimental groups (7th meeting, dual-limited set blocks)

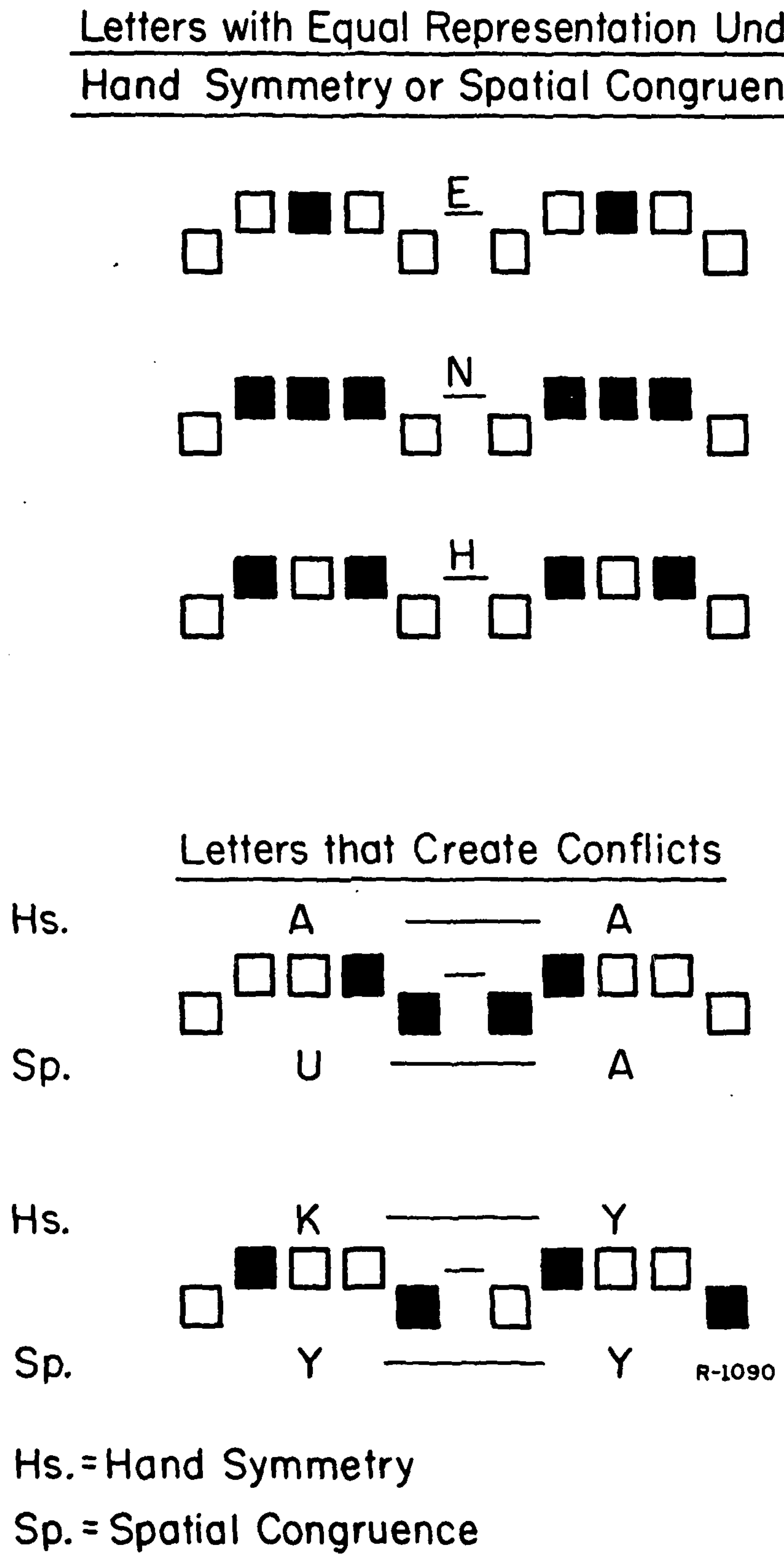

Figure 7 - Examples of letter codes that do not create conflict under any representation principle, and codes that create either spatial or hand symmetry conflict

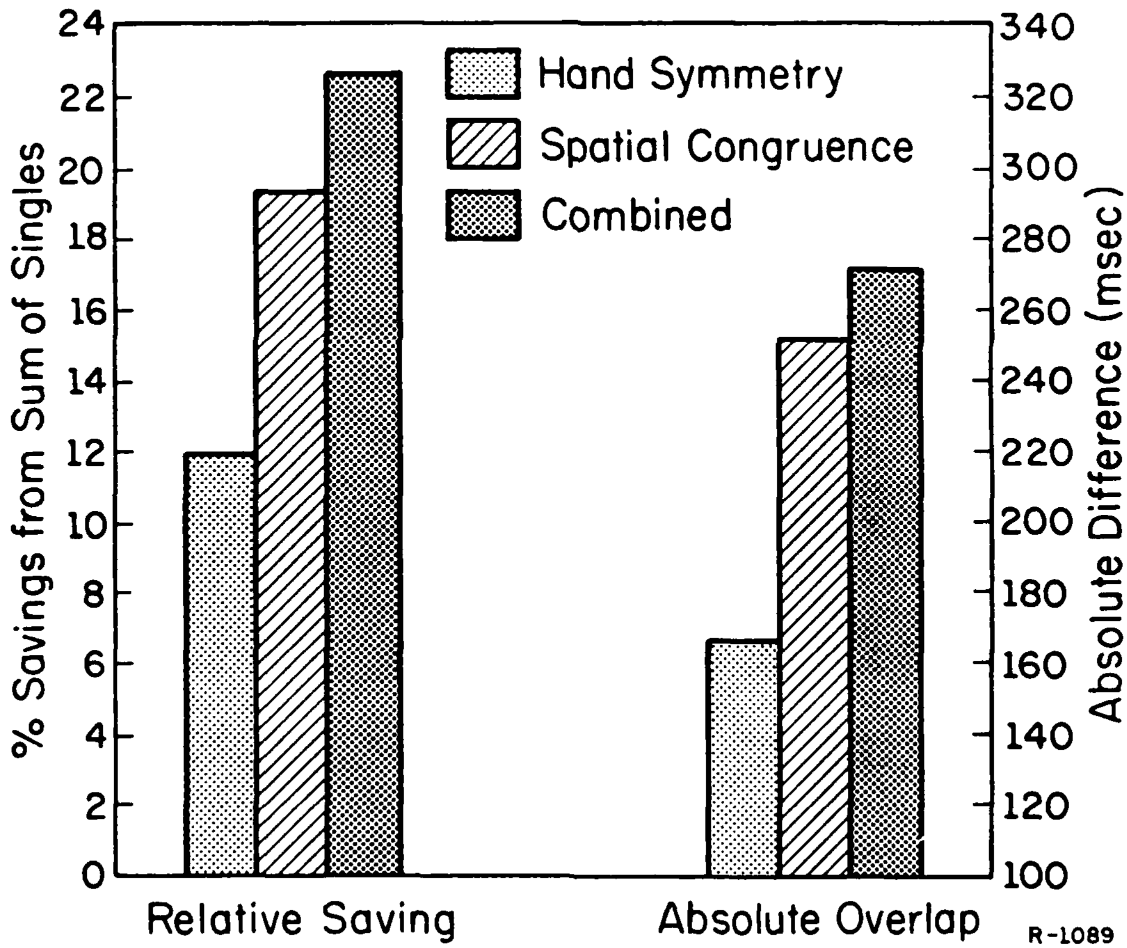

Figure 8 - Relative saving and absolute difference in typing a simultaneous pair of letters as compared with a sequential entry of two letters
(7th meeting)

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